

Performance of forest plantations in small and medium-sized farms in the Atlantic lowlands of Costa Rica

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Abstract

Exotic tree species predominate in reforestation in tropical regions worldwide. However, some native species are suitable for plantations, providing a wider variety of products. Adequate government programs of incentives, coupled with good technical advice to farmers, are needed to stimulate reforestation, especially among small and medium-sized farmers with limited financial resources. This project evaluates growth of native and exotic tree species on plantations in small and medium-sized farms in the Atlantic humid lowlands of Costa Rica, Central America. A total of 210 pure plantations, ranging in age from 6 to 11 years, were evaluated on 123 farms that had used government incentives for reforestation, and had received technical advice from local non-government organizations. For each species, seven plantations were chosen at random for study. In each plantation, plots of 15 trees each were chosen systematically for evaluation of diameter at breast height (dbh), total height, number of trees per hectare, tree form and spacing. *Terminalia amazonia* (J.F. Gmel) Exell, *Hieronyma alchorneoides* Allemao, and *Vochysia guatemalensis* Donn. Sm. were the most frequent species found in plantations in the region of study. *Gmelina arborea* Roxb. (exotic) and *V. guatemalensis* (native) had the highest mean annual diameter increment with 2.90 and 2.59 cm, respectively. *Calophyllum brasiliense* Cambess. (native) had the lowest mean annual diameter increment (1.48 cm). *G. arborea* and *V. guatemalensis* had the highest mean annual volume increment, followed by *Tectona grandis* (L.f) Lam. (exotic), and *T. amazonia* and *Cordia alliodora* (R&P) Cham. (both native). Although *G. arborea* had the greatest mean annual diameter increment, it had the lowest plantation density and problems with form. *V. guatemalensis* and *T. amazonia*, two native species, were the most promising species for reforestation, due to good growth in volume, good form, and adaptability to a variety of sites. The poor form of exotic species was related to the low intensity management methods of small farmers. Exotic species had the highest performance variability between sites, while native species showed relatively high growth homogeneity. Therefore, native species seem more promising than exotics for general use across varying ecological conditions.

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1. Introduction

On a global scale, native species are widely extracted from natural forests. However, use of native species for reforestation is minimal, and exotic tree species predominate both in industrial as well as in rural devel-

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opment plantations (Evans, 1999). In humid tropical regions of Latin America, forest plantations provide wood, as well as various environmental services, such as carbon fixation, soil stabilization, maintenance of biodiversity, and restoration of degraded areas. To ensure success of reforestation programs, farmers must have access to adequate technical assistance for species and site selection. In addition, effective programs of government incentives to stimulate reforestation are needed, especially for small and medium-sized farmers with limited financial resources (Segura, 2000).

In Costa Rica over the past 15 years the supply of wood from natural forests has diminished due to deforestation combined with the establishment of conservation areas (González and Fisher, 1994). In response, more forest plantations have been established for timber, and a number of these have been established by small and medium-sized landowners through credit and government incentives (Watson et al., 1998). Until 1987, one native species (*Cordia alliodora* (R&P) Cham.), and three exotics (*Gmelina arborea* Roxb., *Pinus* spp. and *Eucalyptus* spp.), made up 94% of the plantation production on the Atlantic lowlands of Costa Rica (Dirección General Forestal, 1987).

In Costa Rica studies on native species for use in plantations began in the mid 1980s with research conducted at La Selva Biological Station of the Organization for Tropical Studies (OTS) (Butterfield, 1990; Espinoza and Butterfield, 1990). Their research shows that several native species that had not previously been used for reforestation had good growth and adaptability to degraded soils.

Between 1987 and 1996, the Costa Rican government promoted reforestation through economic incentives, such as the Fund for Forest Development (FDF) and the Forest Payment Certificate (CAF) (Segura et al., 1996; Watson et al., 1998). Farmers in the Atlantic lowlands region, in association with local non-governmental organizations (NGOs): the County Agricultural Center of Sarapiquí (CACSA), and the Foundation for the Development of the Central Volcanic Range (FUNDECOR), began establishing forest plantations. CACSA is an organization made up of small farmers and supported by the Costa Rican Ministry of Agriculture and Livestock (MAG), while FUNDECOR provides technical advice to farmers in sustainable forest management and reforestation. When CACSA and FUNDECOR began working on

reforestation projects, they resorted to the OTS for assistance in species selection. Species were selected for their promising performance and rapid growth (Table 1). With the work of CACSA and FUNDECOR, reforestation in the region passed from a phase of pure investigation to a phase of implementation (FUNDECOR, 2001). By 1999 the projects were responsible for planting approximately 1500 ha in the Atlantic lowlands (FUNDECOR, 2001).

However, the investigations at the Biological Station La Selva, administered by OTS, only covered the first phases of plantation development (3 and 4 years). Information about the long-term performance of the plantations is necessary to guarantee better results and diminish the investment risk for the rural farmers. The objective of the present study was to evaluate the growth of native and exotic tree species in plantations ranging in age from 6 to 11 years. The plantations were established by farmers using government incentives, and with the assistance of the local NGOs in the Atlantic humid lowlands of Costa Rica.

2. Materials and methods

2.1. Site description

The plantations were established between 1990 and 1995 on the Atlantic lowlands of Costa Rica. The study sites are located at 10°12'–10°47' north latitude and 84°09'–83°45' west longitude (Fig. 1). Mean annual temperature is 24 °C. Mean annual precipitation is 3500–5000 mm, and in no month is precipitation less than 50 mm. Elevation is between 30 and 200 m. The overall topography is flat to undulating terrain. In general, soils belong to the Ultisol and Inceptisol orders. There are various limitations of the soil, such as slow or impeded drainage, and very low to medium fertility. These limitations restrict land uses to permanent crops and reforestation. However, projects require careful management because of the area's high susceptibility to erosion (Costa Rica, 1979).

2.2. Characteristics of the farms used in the present research

This study examines 210 pure plantations on 123 farms, as part of a larger study on farmers' preferences

Table 1
Species most used by small and medium farmers in the Atlantic humid lowlands of Costa Rica^a

Species	Family	Natural distribution
<i>Calophyllum brasiliense</i> Cambess	Clusiaceae	Mexico to N. South America
<i>Vochysia guatemalensis</i> Donn. Sm.	Vochysiaceae	Mexico to Peru
<i>Hieronyma alchorneoides</i> Allemao	Euphorbiaceae	Mexico to Brazil
<i>Virola koschnyi</i> Warb.	Myristicaceae	Central America
<i>Cordia alliodora</i> (Ruiz and Pavón) Cham.	Boraginaceae	Mexico to South America
<i>Terminalia amazonia</i> (J. Gmel) Exell.	Combretaceae	S. Mexico to N. South America
<i>Tectona grandis</i> (L.f.) Lam.	Verbenaceae	Asia, Malaysia and Indochina
<i>Dipteryx panamensis</i> (Pittier) Record and Mell	Fabaceae	Nicaragua to Colombia
<i>Gmelina arborea</i> Roxb.	Verbenaceae	South Asia

^a Jiménez and Poveda (1997), and Carpio (1992).

for reforestation in the region (Piotto, 2001). Fig. 2 shows total area planted for each species, and the number of projects established between 1990 and 1995 by the local farmers with assistance from the local NGOs (CACSA and FUNDECOR).

The majority of the farmers (60%) had less than 10 ha, and only 10% had farms larger than 50 ha. The plantations had areas between 0.1 and 5.0 ha. Table 2 shows the size and number of farms where the study areas were located. The majority of the farms were used for agriculture (bananas, plantains, heart of palm, maize, cassava, pineapples, black pepper, and a few ornamentals) (60%), and less for cattle. On 40% of the

farms, the only use of the land was reforestation. The principal previous land use on reforested lands was pastures (57%), followed by agriculture (24%) and young secondary forest (19%). No new areas were deforested for the establishment of the plantations. The farms were primarily on undulating terrain (57%), followed by flat terrain (43%). None of the farms were on steeply inclined terrain.

All the farmers had land titles and received government incentives for plantations (22% FDF and 78% CAF). Incentives were paid in cash and farmers bought supplies for their plantations individually. Economic benefit from harvesting wood was the

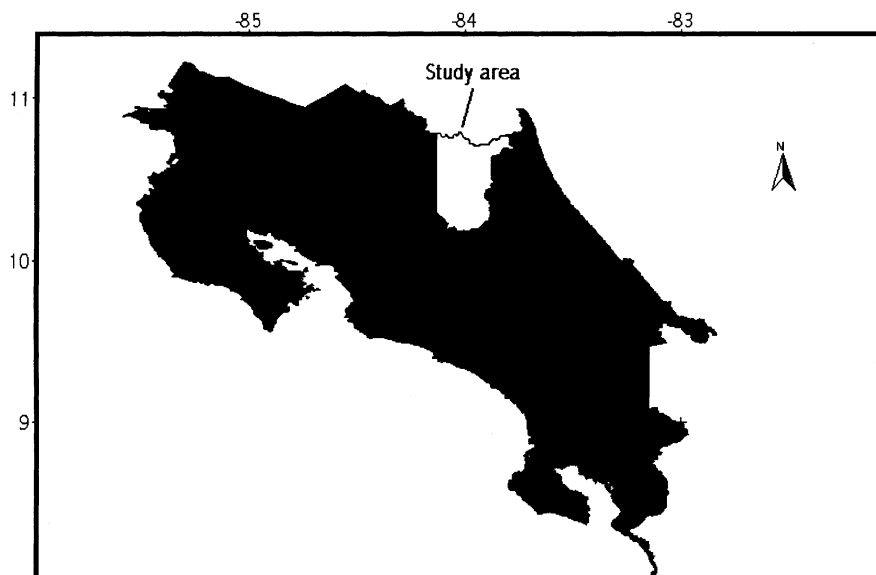


Fig. 1. Map of Costa Rica showing location of study sites.

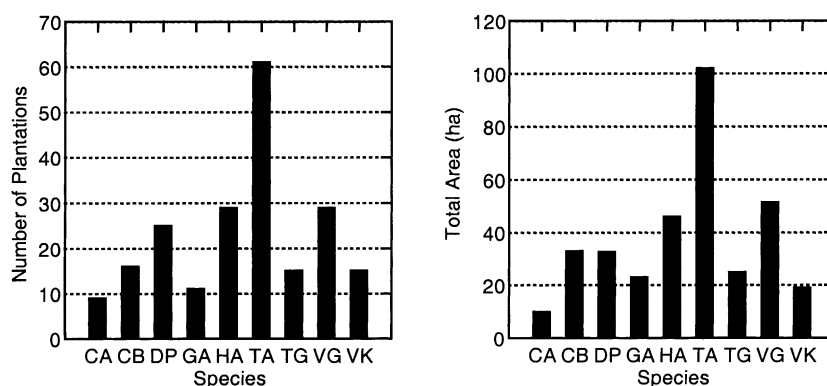


Fig. 2. Number of plantations and total planted area for the species most used by farmers with the assistance of local NGOs in the Atlantic humid lowlands of Costa Rica (plantations established between 1990 and 1995). CA, *Cordia alliodora*; CB, *Calophyllum brasiliense*; DP, *Dipteryx panamensis*; GA, *Gmelina arborea*; HA, *Hieronyma alchorneoides*; TA, *Terminalia amazonia*; TG, *Tectona grandis*; VG, *Vochysia guatemalensis*; VK, *Virola koschnyi*.

motivation of the majority of farmers (62%) (Piotto, 2001). Nonetheless, some of the farmers reforested for environmental reasons (38%). These farmers planned to keep reforested areas as permanent reserves.

2.3. Methods

All plantations in the region were identified and then a random subset of seven plantations was selected for study of each species (9 species $\times$ 7 plantations each = 63 plantations total). The number of plantations was decided in order to obtain a 20% sampling error, which is the highest acceptable error allowed in forest inventories by the Costa Rican government. The study used the mean annual increment of diameter at breast height, dbh variable for *Virola koschnyi* Warb. using data already available for this species from FUNDECOR. This variable was used because the plantations in this study are of different ages. If basal area or volume had been used to study plots of

different ages and different spacing between trees, outcomes would have lacked uniformity.

The following formula was used to calculate the number of plantations needed to perform this study:

$$n = \frac{CV^2 t_{0.05}^2}{SE^2}$$

where n is the number of plantations, CV the coefficient of variation (%), $t_{0.05}$ the values from the Student's t -test at 5% probability, and SE the sampling error (%).

Because of the lack of information for other species, this study used a calculated size of the samples for *V. koschnyi* and applied this value to all species. However, differences between species were expected, and each species had its own sampling error (Table 3). The table shows that only in the *G. arborea* and *Dipteryx panamensis* (Pittier) plantations was sampling error above 20%. Because this study was meant to be an exploratory study comparing growth of different species, the study area was not enlarged to address this problem. Species like *Calophyllum brasiliense* Cambess, which has nearly the same number of plantations as *T. grandis* in the region, had a sampling error of 10%. The species with the largest number of plantations in the area, *Terminalia amazonia* (J. Gmel) Exell, had the lowest sampling error (Table 3).

For this project, a multi-series sampling design was used for each species. The primary units of study were the plantations, chosen at random. The secondary

Table 2

Size and number of farms where tree measurements were taken in the Atlantic humid lowlands of Costa Rica

Farm size (ha)	Number of farms sampled	Mean area of farm sampled (ha)
≤ 10	25	0.98
10–50	13	1.10
>50	5	2.68

Table 3
Survival and number of trees per hectare and sampling error on small and medium farms in Atlantic humid lowlands of Costa Rica^a

Species	Survival (%)	Number of trees/ha	Sampling error (%)
<i>C. brasiliense</i>	87.1 a	840 a	9.8
<i>V. guatemalensis</i>	75.1 a	647 b	10.0
<i>H. alchorneoides</i>	72.4 ab	634 b	10.3
<i>V. koschnyi</i>	72.4 ab	681 ab	12.9
<i>C. alliodora</i>	71.9 ab	693 ab	15.7
<i>T. amazonia</i>	69.0 ab	597 b	16.0
<i>T. grandis</i>	68.0 ab	689 ab	17.0
<i>D. panamensis</i>	66.6 ab	654 b	22.2
<i>G. arborea</i>	59.5 b	653 b	26.8

^a For each variable, differences among means in the same column followed by the same letter are not statistically significant ($P < 0.01$).

units of study were temporary plots of 15 trees each. The 15-tree plots were chosen systematically.

Plots were designed by number of trees because trees on the plantations showed homogenous spacing, but with different arrangements ($3\text{ m} \times 3\text{ m}$, $3.5\text{ m} \times 3.5\text{ m}$ and $4\text{ m} \times 4\text{ m}$). This design guaranteed a uniform number of observations per plot, independent of initial tree spacing. The use of 15-tree plots is suggested by Wright (1964), who compared performance of 15-tree plots with 200-tree plantation plots. Wright demonstrated that both plot sizes gave similarly valid estimations of tree growth relative to height and diameter.

Systematic plot placement was used in this investigation to diminish cost and time related to the investigation. In the majority of the cases, the systematic approach produces more precise results than random sampling (Kleinn and Pérez, 2000). A random procedure was used to place the first corner of the first tree-plot, and the following tree-plot was located 50 m from the initial tree plot. Sampling intensity was four plots per hectare, representing 5.4% of the area where plantations were at $3\text{ m} \times 3\text{ m}$ planting distance, and 9.6% when plantations were at $4\text{ m} \times 4\text{ m}$ spacing.

2.4. Data analysis

In each plot, dbh, total height, number of trees per ha, tree form, and spacing, were evaluated. Trees

were placed in one of the three categories of form (straight stems, slightly sinuous or very sinuous stems). Bifurcation in the stem at height less than 4 m was also recorded. The MIRA-SILV software was used to analyze the field data (Ugalde, 2000). Tree survival, basal area and volume were calculated for each plot. Calculation of volume was done using a 0.5 volume factor (Newbould, 1967). Analysis of variance was used to compare mean annual increments in dbh, height and volume, and survival between species. Means were compared using the Turkey HSD test.

3. Results

3.1. Plantation spacing

Plantations with spacing of $3\text{ m} \times 3\text{ m}$, $3.5\text{ m} \times 3.5\text{ m}$ and $4\text{ m} \times 4\text{ m}$ were found for each species. The most common spacing scheme was $3\text{ m} \times 3\text{ m}$ for all species. For *G. arborea*, $3\text{ m} \times 3\text{ m}$ was the only spacing scheme used. *D. panamensis* was the only species with plantations in all three spacing schemes, including $3.5\text{ m} \times 3.5\text{ m}$.

3.2. Tree survival and number of trees per hectare

Survival of species in this study reflected the percentage of trees remaining in plantations after replanting, thinning and natural mortality. The species with the highest survival was *C. brasiliense*, with 87.1% of the trees initially planted still living. The species with the second highest survival was *V. guatemalensis* with 75.1%. *G. arborea* had the lowest survival with 59.5%. This is a significant difference ($P < 0.01$) when compared with *C. brasiliense* and *V. guatemalensis* (Table 3).

The number of trees per hectare, which represents the density of the stands, had low variation without significant difference between species ($P < 0.01$). The exception to this observation was *C. brasiliense* which had the highest density.

3.3. Tree growth and productivity

Significant differences were found ($P < 0.01$) in mean annual increments in dbh and mean annual

Table 4

Mean annual increment in diameter (MAIDBH), mean annual increment in height (MAIH), mean annual increment of volume (MAIV) and tree form of the nine species most used by small and medium farmers in the Atlantic lowlands of Costa Rica^a

Species	MAIDBH (cm per year)	MAIH (m per year)	MAIV (m ³ /ha per year)	Straight stem (%)	Slightly sinuous (%)	Very sinuous (%)	Forked trees (%)
<i>G. arborea</i>	2.90 (0.49) a	2.24 (0.42) a	31.49 (14.3) a	86.2	12.2	1.6	0.8
<i>V. guatemalensis</i>	2.59 (0.29) a	1.90 (0.26) b	23.51 (13.0) ab	96.8	2.6	0.6	1.3
<i>T. amazonia</i>	2.36 (0.25) ab	1.97 (0.31) ab	17.66 (7.16) bcd	96.6	3.4	0.0	7.6
<i>T. grandis</i>	2.36 (0.57) ab	1.88 (0.42) b	21.39 (12.7) b	78.9	17.6	3.5	8.5
<i>C. alliodora</i>	2.09 (0.38) bc	1.68 (0.32) bc	15.67 (6.36) bcde	86.0	12.0	2.0	4.0
<i>V. koschnyi</i>	1.95 (0.34) bc	1.41 (0.37) c	11.47 (7.67) cdef	100.0	0.0	0.0	0.0
<i>H. alchorneoides</i>	1.85 (0.26) bc	1.71 (0.27) bc	10.21 (6.13) def	84.0	15.3	0.7	14.7
<i>D. panamensis</i>	1.73 (0.50) c	1.94 (0.47) ab	7.90 (4.39) ef	89.2	10.1	0.7	5.8
<i>C. brasiliense</i>	1.48 (0.16) c	1.29 (0.19) c	5.95 (3.13) f	95.1	4.9	0.0	4.4

^a Differences among means for each variable are statistically significant when the standard deviation is followed by different letters ($P < 0.01$).

increments in height between species (Table 4). *G. arborea* and *V. guatemalensis* were the species with greatest mean annual dbh increments, with 2.90 and 2.59 cm, respectively. Differences among these growth rates were highly significant ($P < 0.01$) when compared with other species in the study. *T. amazonia* and *T. grandis* were the exceptions, with similar dbh growth of 2.36 cm per year. *C. brasiliense* had the lowest mean annual dbh increment (1.48 cm). This was significantly inferior ($P < 0.01$) to other species, with the exceptions of *Hieronyma alchorneoides* Allemao and *D. panamensis* (with 1.85 and 1.73 cm, respectively).

G. arborea, *T. amazonia* and *D. panamensis* had the largest mean annual increment in height with 2.24, 1.97 and 1.94 m, respectively. *G. arborea* and *V. guatemalensis* had the highest mean annual increment in volume, followed by *T. grandis*, *T. amazonia* and *C. alliodora*. *C. brasiliense* and *D. panamensis* had the lowest mean annual increment in volume.

3.4. Tree form

V. koschnyi and *V. guatemalensis* had the highest proportion of straight stems, and the lowest proportion of sinuous or bifurcated trees. *H. alchorneoides* and *T. grandis* had the highest percentages of bifurcated stems with 14.7 and 8.5%, respectively. *G. arborea* also had inferior stem form when compared with native species, despite being the species with the highest growth (Table 4).

4. Discussion

4.1. Promising species for reforestation: productivity and economic and environmental values

Use of exotic species predominates in tropical timber and rural development plantations worldwide (Evans, 1999). However, in the Atlantic lowlands of Costa Rica, 88% of plantations established between 1990 and 1995 used native species. The high use of native species in the region is largely due to the results of tree planting projects at La Selva Biological Station, as well as to the technical assistance regarding species selection provided to farmers by the local NGOs. Projects at La Selva demonstrated that some native species, which had not previously been used for reforestation, were in fact appropriate for silviculture (Butterfield, 1990; Espinoza and Butterfield, 1990). In addition, the government subsidies provided at the time were effective in promoting reforestation with native species by small and medium farmers throughout the region.

The results of this investigation show that the majority of plantations in the area had grown well, and some advantages of using native species over exotics were apparent. Although an exotic species (*G. arborea*) had one of the greatest annual growth in dbh and height, it had the lowest plantation density and problems with tree form. This species has been studied extensively in the neotropics, and similar results have previously been reported in Costa Rica

(Centro Agronómico Tropical de Investigación and Enseñanza, 1991; González and Fisher, 1994).

Vochysia guatemalensis and *T. amazonia* were the most promising native species for reforestation, with annual growth comparable to the most commonly used exotic species (Martínez, 1981). Similar results for younger trees of these species have been reported in other studies conducted in the same region (Butterfield and Espinoza, 1995; González and Fisher, 1994; Espinoza and Butterfield, 1990). The results of this investigation are therefore, in accordance with previous projects, demonstrating the viability of using native species for timber-producing reforestation in the region. Although at present the total rotation times for these species are not known, expected volumes at harvest are estimated as 170 m³/ha for *T. amazonia* after 25 years, and 250 m³/ha for *V. guatemalensis* after 20 years (Montagnini, 2001). These yields make them attractive alternatives for farmers. Fuelwood from thinnings represents an additional source of income for the farmers (Montagnini and Mendelsohn, 1997).

The four species with best growth were two native species (*V. guatemalensis* and *T. amazonia*) and two exotics (*G. arborea* and *T. grandis*). Nonetheless, when comparing tree form, native species were superior. The poor form of exotic species could be related to the low intensity of management applications by small farmers (Haggar et al., 1998). Normally, these exotic species require intensive management to guarantee productivity and high wood quality.

In the present research, for each exotic species, there is a native species that is comparable in wood quality and growth. *G. arborea* (exotic) and *V. guatemalensis* (native) produce light wood with specific weight of approximately 0.34 and 0.35 g/cm³, respectively. *T. grandis* (exotic) and *T. amazonia* (native) produce heavier wood, with mean specific weights of 0.61 and 0.68 g/cm³, respectively (Carpio, 1992). Use of native species, which are better adapted to local conditions, instead of exotics is one way to maintain wood production and increase the conservation value of plantations (Keenan et al., 1999; Parrotta et al., 1997). In addition, native species are better suited to low-input forestry practices (Haggar et al., 1998), common on small and medium-sized farms in tropical regions.

D. panamensis and *C. brasiliense* had the lowest growth in dbh and height, and could be classified as

slow-growing species. These species need long rotation periods to produce saw timber. Estimated rotation times are 35–40 years, with estimated volumes at harvest of 200 m³/ha for *C. brasiliense* and 300 m³/ha for *D. panamensis* (Montagnini, 2001). *C. brasiliense* was the slowest growing species, with growth rates slightly lower than those found by Butterfield and Espinoza (1995) and by Montagnini et al. (1995) in 4-year-old pure plantations. Nonetheless, many small farmers have chosen to plant these species because of the high priced wood and their good form. The high value of the wood compensates for the low annual increments in volume. These species also have a high social and environmental value. *D. panamensis* seeds are an important food source for fauna, including the green macaw (*Ara ambigu*) (an endangered species) and some rodents like *Sciurus granatensis*, *Dasyprocta punctata*, *Agouti paca*, and *Proechimys semispinosus*. *D. panamensis* also contributes to the establishment of other vegetation because of its interactions with several seed dispersers and pollinators (Bonaccorso et al., 1980; Terborgh and Wright, 1994).

H. alchorneoides, *C. alliodora* and *V. koschnyi* are other native species that had relatively good growth, although lower than the exotic species (*G. arborea* and *T. grandis*) and than the other more productive native species of this research, such as *V. guatemalensis* and *T. amazonia*. *H. alchorneoides* has a relatively high percentage of bifurcated trees (14.7%) and some problems with tree form. However, estimated revenues from harvesting *H. alchorneoides* are high due to relatively high market prices, making its planting an attractive alternative (Montagnini and Mendelsohn, 1997). This species requires intensive management during initial phases of a plantation development, such as pruning, to guarantee higher quality stems for final harvest. Nonetheless, for small farmers interested in high value timber, these species could be used to obtain a greater variety of products to respond to market uncertainty (Montagnini et al., 1997).

4.2. Effects of site and silvicultural practices on species performance

The sites where the plantations were established are marginal lands for traditional agriculture because of their poor and degraded soils. In these zones, as in many regions of the humid tropics worldwide, forestry

activities are relatively new, and are generally practiced by small and medium farmers (5–50 ha farms). These farmers generally use low inputs, give little preparation to the sites, and manage the plantations with low intensity. Varying site conditions and low intensity management can create a high variability in productivity of the same species on different plantations. For higher growth homogeneity across plantations, foresters should use more stable genotypes (Butterfield, 1996). That is, genotypes that maintain a certain level of productivity across varying conditions should be used. Using dbh, mean annual height increment, and variance between plantations (S_2)

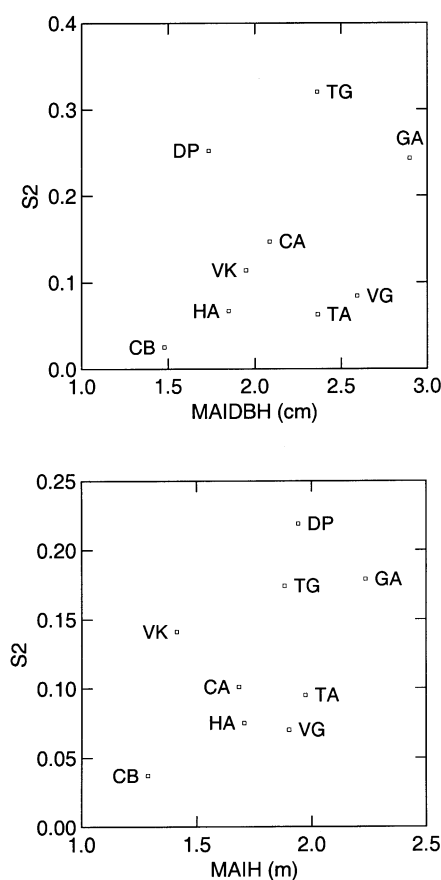


Fig. 3. Variance (S_2) versus mean annual increment in dbh (MAIDBH) and mean annual increment in height (MAIH) for the nine species most used by farmers in the Atlantic humid lowlands of Costa Rica. CA, *Cordia alliodora*; CB, *Calophyllum brasiliense*; DP, *Dipteryx panamensis*; GA, *Gmelina arborea*; HA, *Hieronyma alchorneoides*; TA, *Terminalia amazonia*; TG, *Tectona grandis*; VG, *Vochysia guatemalensis*; VK, *Virola koschnyi*.

(Fig. 3), this study provides insight as to which species have higher performance homogeneity.

Exotic species had the highest performance variability across sites and under different management plans. Exotic species had relatively higher growth in height and dbh, but also had high variability between sites (Fig. 3). These findings indicate that these exotic species could be considered “specialists”, i.e., site variability and management have a substantial impact on growth and development of these species. Nonetheless, if the variables affecting growth could be identified, the exotic species could be planted in adequate sites and managed in a way to maximize productivity (Butterfield, 1996).

On the other hand, native species had relatively high growth homogeneity across the entire study area, with the exception of *D. panamensis*. Native species seem more promising than exotics for general use across varying ecological conditions. For example, *V. guatemalensis* and *T. amazonia*, in addition to having similar growth rates to the exotic species and good expected volume yields at harvest, displayed high plasticity in relation to site conditions. These two species seem to be the best alternative for local plantations, as well as for plantations in other regions with similar ecological conditions.

The rest of the native species, which displayed relatively lower growth rates but high plasticity, could be used on less favorable sites. These species should be planted on soils that are compacted from previous land use, have poor drainage, low fertility, and in areas where there is limited management.

4.3. Farmer objectives and needs for the promotion of reforestation

Previous studies indicate that many farmers throughout the tropics perceive reforestation as a way to make marginal farm areas productive, both environmentally and economically (Díaz, 1995; Korhonen, 2000). The primary objective of plantations in this study was to bring economic benefits to farmers and increase forest products for farm use. Environmental objectives have prevailed in importance in previous studies in Costa Rica (Martínez et al., 1994; Current and Scherr, 1995; Díaz, 1995; Schelhas et al., 1997; Thacher et al., 1997). A farmer's objective in establishing a plantation is associated to his/her

economic situation and level of education. Poorer farmers plant trees for economic benefit and domestic needs. Current and Scherr (1995) found that economic benefit is the primary reason for the establishment of plantations in Central America, where high levels of poverty predominate, especially in rural areas (Kaimowitz, 1996).

Most farmers in the region believe that the government established forest policy for long-term planning (Piotto, 2001). They believe that the government must guarantee financial support to ensure that plantations complete a productive rotation. The government must also simplify bureaucratic procedures for distribution of incentives. Many studies have demonstrated that in most developing countries, projects developed and maintained with incentives are not sustainable after financial support ends (Roche, 1997).

The forestry sector needs greater emphasis on social implications of reforestation, especially because incentives tend not to benefit the poorest farmers (Watson et al., 1998). Small scale reforestation projects are apparently more expensive, but small projects are a better way to distribute benefits. Without financial support, forest resources on farms will continue to be managed unsustainably.

Farmers in the Atlantic lowlands of Costa Rica are willing to continue reforestation (Piotto, 2001). Forestry is commonly perceived to provide many goods and services. However, farms have low income, limiting the establishment of plantations due to long rotations and high risk (Segura, 2000). Therefore, programs and projects to support reforestation on small farms should be improved to satisfy social, economic and environmental goals.

5. Conclusions

Widespread use of native species for reforestation programs in the Atlantic lowlands of Costa Rica was, as the results of this study show, a good decision. Native species had better or equal performance than exotic species, and also had greater adaptability to a variety of site conditions than exotic species. Use of native species helped create greater production diversification on the plantations. Also, the use of medium and high quality native species in reforestation projects can alleviate logging pressure on natural forests.

The majority of native species used demonstrated high potential productivity for commercial plantations. The native species, particularly *V. guatemalensis* and *T. amazonia*, showed rapid growth, high survival rates, and plasticity to respond to different site conditions. Therefore, these species could also be used successfully in reforestation in other regions with similar ecological conditions. Programs for genetic improvement should be considered to increase productivity and reduce rotation cycle length. Further work to improve native species for commercial use will make them more attractive to small farmers, and reduce the need for government incentives.

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References

- Bonaccorso, F.J., Glanz, W.E., Sandford, C.M., 1980. Feeding assemblages of mammals at fruiting *Dipteryx panamensis* (Papilionaceae) trees in Panama: seed predation, dispersal, and parasitism. *Rev. Biol. Trop.* 28, 61–72.
- Butterfield, R., 1990. Native species for reforestation and land restoration: a case study from Costa Rica. In: *Proceedings of the 14th IUFRO World Congress*, Vol. 2, Montreal, Canada, pp. 3–14.
- Butterfield, R., 1996. Early species selection for tropical reforestation: a consideration of stability. *For. Ecol. Manage.* 81, 161–168.
- Butterfield, R., Espinoza, M., 1995. Screening trial of 14 tropical hardwoods with an emphasis on species native to Costa Rica: fourth year results. *New For.* 9, 135–145.
- Carpio, I.M., 1992. *Maderas de Costa Rica: 150 especies forestales*. Universidad de Costa Rica, San José, Costa Rica, p. 338.
- Centro Agronómico Tropical de Investigación and Enseñanza, 1991. *Melina (Gmelina arborea): especie de árbol de uso múltiple en América Central*. Ser. Téc., Colección Guías Silviculturales No. 10. CATIE, Turrialba, Costa Rica, p. 62.
- Costa Rica, 1979. *Manual descriptivo de los criterios, clases and subclases del mapa "Capacidad de uso de los suelos de Costa Rica"*. Oficina de Planificación Sectorial Agropecuario, San José, Costa Rica, p. 100.
- Current, D., Scherr, S., 1995. Farmer costs and benefits from agroforestry and farm forestry projects in Central America and Caribbean: implications for policy. *Agrofor. Syst.* 30, 87–103.

- Díaz, Y.V., 1995. Socioeconomía y silvicultura del establecimiento de plantaciones forestales en fincas pequeñas del Cantón de Pérez Zeledón, Costa Rica. Tesis M.Sc. CATIE, Turrialba, Costa Rica, p. 94.
- Dirección General Forestal, 1987. Boletín estadístico No. 2. Dirección General Forestal, San José, Costa Rica, p. 5.
- Espinoza, M., Butterfield, R., 1990. Adaptabilidad de 13 especies nativas bajo condiciones de plantación en las tierras bajas húmedas de Costa Rica. En: Salazar, R. (Ed.), Manejo y Aprovechamiento de Plantaciones Forestales con Especies de Uso Múltiple. Actas Reunión IUFRO, Guatemala, Abril de 1989. CATIE, Turrialba, Costa Rica, pp. 159–172.
- Evans, J., 1999. Planted forests of the wet and dry tropics: their variety, nature, and significance. *New For.* 17, 25–36.
- FUNDECOR, 2001. Programas y su impacto: reforestación. Consulted 28 May 2001. Available in <http://www.fundecor.or.cr/logros/programas/reforestacion.shtml>.
- González, E., Fisher, R., 1994. Growth of native species planted on abandoned pastureland in Costa Rica. *For. Ecol. Manage.* 70, 159–167.
- Haggar, J.P., Briscoe, C.B., Butterfield, R.P., 1998. Native species: a resource for the diversification of forestry production in the lowland humid tropics. *For. Ecol. Manage.* 106, 195–203.
- Jiménez, Q., Poveda, L.J., 1997. Lista actualizada de los árboles maderables de Costa Rica. Aportes al Desarrollo Sostenible. Universidad Nacional, Heredia, Costa Rica, p. 36.
- Kaimowitz, D., 1996. Livestock and deforestation. Central America in the 1980s and 1990s: a policy perspective. CIFOR Special Publication. Center for International Forestry Research, Bogor, Indonesia.
- Keenan, R.J., Lamb, D., Parrotta, J., Kikkawa, J., 1999. Ecosystem management in tropical timber plantations: satisfying economic, conservation, and social objectives. *J. Sustain. For.* 9, 117–134.
- Kleinn, C., Pérez, J., 2000. Consideraciones metodológicas en la experimentación científica agrícola. Sub-Unidad de Estadística. CATIE, Turrialba, Costa Rica, p. 28.
- Korhonen, K., 2000. The silvicultural state of planted forests in southern Costa Rica as affected by farmers' motivation for reforestation: evaluation of forest incentive programs. Thesis. University of Helsinki, Finland, p. 71.
- Martínez, H.H., 1981. Evaluación de ensayos de especies forestales en Costa Rica. Tesis. CATIE, Turrialba, Costa Rica, p. 172.
- Martínez, H.A., Sage, L.F., Borge, C., Picado, W., 1994. Evaluación técnica externa del Programa de Desarrollo Forestal. DGF-DECAFOR. Secretaría Técnica de Apoyo. Fondo de Desarrollo Forestal, San José, Costa Rica, p. 120.
- Montagnini, F., 2001. Plantaciones forestales con especies nativas: una alternativa para la recuperación de áreas degradadas. *Biocenosis (Costa Rica)* 15 (1–2), 72–78.
- Montagnini, F., Mendelsohn, R., 1997. Managing forest fallows: improving the economics of swidden agriculture. *Ambio* 26, 118–123.
- Montagnini, F., González, E., Rheingans, R., Porras, C., 1995. Mixed and pure forest plantations in the humid neotropics: a comparison of early growth, pest damage and establishment costs. *Commonw. For. Rev.* 74, 306–314.
- Montagnini, F., Sancho, F., González, E., Porras, C., Moulart, A., Mónaco, A., 1997. Plantaciones forestales puras y mixtas con especies nativas para la reforestación de terrenos degradados en Costa Rica: estudio comparativo del crecimiento, daño por plagas, regeneración natural y costos de establecimiento. *Biocenosis (Costa Rica)* 12, 25–34.
- Newbould, P.J., 1967. Methods for Estimating the Primary Production of Forest. IBP Handbook 2. Blackwell Scientific Publications, Oxford, UK.
- Parrotta, J.A., Turnbull, J.W., Jones, N., 1997. Catalyzing native forest regeneration on degraded tropical lands. *For. Ecol. Manage.* 99, 1–7.
- Piotto, D., 2001. Plantaciones forestales en Costa Rica y Nicaragua: Comportamiento de las especies y preferencias de los productores. Tesis M.Sc. CATIE, Turrialba, Costa Rica.
- Roche, L., 1997. Official development aid policies and sustainable utilization of forest resources in developing countries. *Commonw. For. Rev.* 76, 91–97.
- Schelhas, J., Jantzi, T., Kleppner, C., O'Connor, K., Thatcher, T., 1997. Costa Rica: meeting farmers needs through forest stewardship. *J. For.* 95, 33–38.
- Segura, O., 2000. Sustainable systems of innovation: the forest sector in Central America. SUDESA Research Papers, 24. Department of Business Studies, Aalborg, Denmark.
- Segura, O., Miranda, M., Mejías, R., 1996. Planificación e inversión en el sector forestal en Costa Rica. Consejo Centroamericano de Bosques y Áreas Protegidas, Heredia, Costa Rica, p. 32.
- Terborgh, J., Wright, S.J., 1994. Effects of mammalian herbivores on plant recruitment in two neotropical forests. *Ecology* 75, 1829–1833.
- Thacher, T., Lee, D.R., Schelhas, J.W., 1997. Farmer participation in reforestation incentive programs in Costa Rica. *Agrofor. Syst.* 35, 269–289.
- Ugalde, L., 2000. El sistema MIRA, Componente de Silvicultura. Manual del usuario. CATIE, Turrialba, Costa Rica, p. 82.
- Watson, V., Cervantes, S., Castro, C., Mora, L., Solís, M., Porras, I.T., Cornejo, B., 1998. Abriendo espacio para una mejor actividad forestal. Estudio de Costa Rica. Centro Científico Tropical e Institute for Environment and Development, San José, Costa Rica, p. 114.
- Wright, J.W., 1964. Mejoramiento genético de los árboles forestales. FAO, Rome, p. 437.